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Fishing Grounds and the Invasive Species Impact: a Case Study in a Coastal Brazilian Watershed

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HIGHLIGHTS

- Non-native fish species introduction by fishing grounds escapes.
- High risk of invasion to African catfish, Nile Tilapia, Carp and Trahira.
- Cultivation of low-risk species such as Tambaqui and Pacu is encouraged.

Abstract: one of the leading causes of global biodiversity loss is the introduction of non-native species with high potential for invasion, and fish farms are largely responsible for introducing these species into continental aquatic ecosystems. To assess the possible impacts caused by the introduction of fish species from fishing grounds in natural areas in the Baixada Santista watershed (São Paulo, State, Brazil), the *Aquatic Species Invasiveness Screening Kit* (AS-ISK) was used. The study showed that escaped species, primarily caused by the water drainage system of fishing ground tanks and dispersion by birds, can cause significant damage to the conservation of native species. Therefore, it is imperative to establish management practices for cultivated species and frequently monitor the physical-chemical and microbiological parameters of water quality in ponds. African catfish (*Clarias gariepinus*), Nile Tilapia (*Oreochromis niloticus*), Carp (*Cyprinus carpio*) and Trahira (*Hoplias malabaricus*) showed a high risk of invasion. Conversely, Tambaqui (*Colossoma macropomum*) was classified as medium risk, highlighting the importance of this species for breeding in fish farming systems and recreational fishing activities conducted in fishing grounds.

Keywords: Fish; Continental Fish; Fisheries; Exotic Species.

INTRODUCTION

Biological invasions and the extent of invasion events have been increasing worldwide [1], particularly for non-native freshwater fish [2]. This increase is mainly caused by human activities such as trade and transport of goods and people [3, 4]. Invasive species threaten biodiversity, alter ecosystem processes, and negatively impact the economy and human well-being [1, 3, 5, 6, 7, 8]. Intentional introductions have economic and social purposes since they aim to use certain species in production systems, captivity, and for ornamental and recreational purposes. Accidental or unintentional introductions occur through commercial activities or trips [2]. Regardless of the introduction configuration, the invasion of exotic species is recognized worldwide as one of the main factors responsible for biodiversity loss, being the second major cause after habitat degradation [1]. In isolated environments (e.g., islands) and regions with high endemism, introducing exotic species has even greater effects regarding the loss of biological diversity [9, 10].

Regarding aquatic ecosystems, the problem can easily become generalized, as a species introduced in one region can gain free access to others. When these areas communicate, such as Conservation Units, the impacts tend to be immeasurable. The problems and negative interactions caused by the introduction of non-native species can lead to the loss of native ichthyofauna and ecological services, competition for resources, exacerbated predation caused by piscivore species, the introduction of pathogens and parasites, in addition to the modification they can cause in habitat, hybridization, and economic damage [11, 12, 13].

Brazil has one of the richest biodiversities in the world, accounting for around 20% of the world's biota [14, 15]. It is estimated that there are about 55,000 species of vertebrates worldwide, of which approximately 28,000 are fish [16]. The neotropical region has the world's greatest diversity of freshwater fish [17], with about 30% of all freshwater ichthyofauna diversity [18]. The actual Brazilian ichthyofauna is reported to have 4,732 species, composed of around 3,497 species of freshwater and 1,264 marine species (https://www.fishbase.se/search.php). Nevertheless, fish are strongly threatened by anthropic interferences, which put all fish diversity at risk and make it difficult to adopt preservation and conservation strategies [19, 20].

Exotic species are part of the current economic model and have great importance in world food production, such as in agriculture and aquaculture [21]. Although piscicultures are far-reaching in protein/food production, they are the primary introducers of exotic species in natural courses, either through intentional loosening or accidental escapes [22, 23, 24]. In Brazilian pisciculture, more than half of the production is represented by a group of invasive alien species, the Tilapia. According to the IBGE Municipal Livestock Survey (PPM), in 2019, Tilapia production accounted for 61% of a total of 529,600 tons of fish produced, and its production has grown annually. The southern and southeastern regions of the country are the largest producers of Tilapia, with the Paraná State being at the forefront, followed by São Paulo and Minas Gerais [25]. Fishkeeping also contributes on a large scale to the introduction of fish exotic species [26]. Another type of trade that has grown a lot, especially since the 1990s, was fishing grounds - establishments linked to sport fishing, amateur fishing, and leisure.

Brazil has a total of 12 hydrographic regions [27] with a vast biodiversity of aquatic species [28]. About 60% of these species are in an overfishing situation [29]. Coastal areas are regions with a high diversity of ecosystems. The abiotic and biotic characteristics of these regions are remarkable for the maintenance and balance of the entire biosphere [30]. The Baixada Santista watershed is a coastal basin located on the central coast of the São Paulo State and suffers the interference of various ecosystem stressors, from the pollution of its waters due to the intense industrial and port activity exerted in the region [31, 32, 33], as well as the breeding of fish in captive conditions in order to meet both the demand for consumption, as well as for sport fishing practices. Depending on their location, type, and precariousness of the facilities of the breeding spaces, fishing grounds can be configured as potential introducers of exotic species in a region. Thus, considering that fishing grounds usually have rustic spaces, where many managers of this type of enterprise do not have basic knowledge about good management practices, laws and much less about the potential ecological impact related to the introduction of non-native species [22, 34, 35], it is essential to evaluate the potential for invasion of fish species cultivated in these regions.

The adoption of measures aimed at avoiding or reducing the impact of invasive species is of utmost importance. Therefore, many decision support tools have been developed to help assess the risk of invasion of non-native species. One of the decision support tools developed is the Aquatic Species Invasiveness Screening Kit (AS-ISK), a program that seeks to categorize the impacts caused by the introduction of exotic species in aquatic environments, considering their bioecological aspects and the effect of climate change [36, 37]. In this study, the AS-ISK decision support tool was used to evaluate the risk of invasion of non-native fish species cultivated in fishing grounds located in the River Basin of Baixada Santista (São Paulo State Brazil). The study involved the identification of fish species cultivated and commercialized in the fishing grounds of the Baixada Santista watershed, the evaluated fishing grounds as possible introducers of exotic species, the categorization of fish species according to their potential risk of invasion, and the identification of possible impacts regarding the introduction on the commercial and environmental sectors.

MATERIAL AND METHODS

Study area

Brazil is divided into 12 hydrographic regions (HR), which the São Paulo State encompassing three of them: South Atlantic, Southeast Atlantic, and Paraná [27]. The Southeast Atlantic HR covers 2.5% of the national territory, while the South Atlantic HR covers 2.2% and includes municipalities in São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul States. The Paraná HR covers 10% of the national territory, totaling 2,583,000 Km, and includes the states of São Paulo, Paraná, Rio Grande do Sul, Minas Gerais, Mato Grosso do Sul, Goiás, Santa Catarina, and the Federal District. This region has the highest demand for water, economic development, and human population [27]. In São Paulo State, water resources are grouped into 22 watersheds, with freshwater fish distributed among four sub-basins: Alto Paraná, Paraíba do Sul River, Ribeira de Iguape River, and Baixada Santista. Apart from the Alto Paraná, which is mainly located in the Cerrado Biome (except for the Alto Tietê sub-basin that drains into the Atlantic Forest region), the other three watersheds drain almost entirely into the Atlantic Forest [38].

The Baixada Santista watershed is a coastal basin where small drainages occur in the coastal strip and flow directly into the Atlantic Ocean. The Baixada Santista watershed is part of the Water Resources Management Unit 07 (UGHI 07), covering a total area of 2,422.776 km², with a drainage area of 2,818 km², and includes nine municipalities: Santos, Bertioga, Cubatão, Guarujá, Itanhaém, Mongaguá, Peruí, Praia Grande and São Vicente. The main rivers in this basin are Cubatão, Jurubatiba, Mogi, Quilombo, Itapanhaú, Guaratuba, Guaraú, Mambú, Aguapeú, and Preto [39, 40]. As a coastal region, fishing resources are abundant in the daily life of the residents of Baixada Santista, due to the marine environment and the coastal ecosystems that surround them. Located in the central part of the São Paulo coast, Baixada Santista is a densely populated region, with about 1,831.884 inhabitants [41], although this number doubles during the holiday season. In addition to intense tourism, the region has experienced significant pollution due to the industrial activity concentrated mainly in Cubatão city [31, 32]. The area is home to about 1,100 factories operating in various segments such as metallurgy, steel, and the production of raw materials for the chemical industry. It is also home to the largest port in Latin America [33]. As a result, the Baixada Santista region is subjected to multiple ecosystem stressors.

Survey of species grown in fishing grounds and compilation of secondary data

An initial search was conducted on *Google Maps* to obtain information about the fishing grounds, and preliminary data about fish species was obtained directly from the establishment managers. After identifying and confirming the main commercialized species through sport fishing and “fish and pay”, a systematic search was conducted to compile data on the ecology, biology, and biogeography of the species to assess the risk of invasion. For each species, a systematic search was undertaken using two main sources of information: 1) the Web of Science, (https://login.webofknowledge.com/); 2) Google Scholar (https://scholar.google.com.br/), to access; 3) SciELO (*Scientific Electronic Library Online* - https://www.scielo.org/); 4) CAPES Periodic platform (https://www.periodicos.capes.gov.br/), to access peer-reviewed publications and scientific abstracts from conferences, peer-reviewed, grey literature, and web-based information, respectively. In addition, technical bulletins and peer-reviewed publications deposited in the Instituto de Pesca (https://www.pesca.sp.gov.br/serie-relatorios-tecnicos; https://institutodepesca.org/index.php/bip) were also consulted. FishBase (www.fishbase.org; Froese & Pauly, 2022) was also used to obtain general information about the species. Boolean search terms such as AND, NOT, and OR were used to unify the search effort for each question/species combination. After identifying appropriate publications, an assessment of the information contained therein was used to highlight additional sources of information.

Interviews

To determine the potential impact of fishing grounds in the area of risk assessment, such as fish introduction, and to obtain more information about the cultivated species in these establishments, the managers were given a semi-structured form comprising 27 questions, between alternative (n = 14) and discursive options (n = 13), covering aspects related to general data, fish species cultivated, animal health perception, fisheries management practices adopted, and understanding of the ecological impacts of introduction of non-native species into the environment. Together with the compiled data from the literature review, these data were also used in the AS-ISK, to improve the confidence of the answers to obtain the invasiveness potential risk of each fish species.

The number of interviews was based on an exploratory search on the Google Maps platform, on the number of fishing grounds in the hydrographic basin proposed for study (n = 7). However, in the field, it was observed that some fisheries closed because of the Covid-19 pandemic. In the field, the interviews were only started after the interviewee agreed to participate in the research via the Free and Informed Consent Term (FICT), which presented the conditions for voluntary participation in the research, the guarantee of anonymity, and the possibility of the interviewee to withdraw at any stage of the research. The questions were read orally by the researcher, using a dialogic approach. For the compilation and analysis of the results, the data obtained were grouped based on the respondent's situation and fish and fishing grounds characteristics.

Invasion risk analysis

The invasiveness potential of each species was undertaken using the AS-ISK v2.3.3, available for free download at www.cefas.co.uk/nns/tools. The AS-ISK allows the analysis of the invasion potential of exotic species of freshwater fish, in addition to other taxonomic groups, considering bioecological and biogeographic aspects, as well as aspects related to climate change [36].

The risk assessment area specific calibration is a statistical procedure based on Receiver Operating Characteristic (ROC) curve analysis [44]. The AS-ISK comprises 55 questions (Qs), asked in 3 sections: 1) Biogeography/Invasion history (n= 13); 2) Biology/Ecology (n=36); and 3) Climate change (n=6), each divided into different categories, dealing with domestication, distribution, and the risk of introduction of the taxonomic group, undesirable traits or persistence, resource exploitation, reproduction and dispersal mechanisms of the taxon and climate change in the assessment area. The first and second sections compose the basic risk assessment (BRA) score. Concluded the BRA score is added to the score from the climate change questions to achieve a composite BRA + Climate Change Assessment (CCA) score (BRA+CCA). To get valid answers, for each question, the assessor must provide a response, justification, and confidence level, classified on a scale of 1 to 4 (1=low; 2=medium; 3=high, 4=very high), recommended by the Intergovernmental Panel on Climate Change [36, 42]. Based on the answers and their confidence degree, the interpretation of the data through the platform (AS-ISK) generated the so-called "rank", characterizing the studied species at different levels of harmfulness and the degree of impact of these in the commercial and environment in the risk assessment area. Therefore, species are classified according to scores ranging from -20 to 70 for the BRA, and -32 to 82 for BRA + CCA. To categorize the risk of invasion of the screened species, the generalized threshold of 18.4 for freshwater fishes in tropical climates was used [37].

Considering the confidence level applied to each answer for a given species, an overall confidence factor was calculated according to the formula:

$$CF = \Sigma \frac{(CL_{Qi})}{(4 \times 55)}$$

Where: CF = confidence factor; CL = confidence level (1=low; 2=medium; 3=high, 4=very high); *i* = 1, …, 55; Q = Question; 4 = maximum achievable value for certainty; 55 = Total number of questions. The CF ranges from a minimum of 0.25 (i.e., all 55 questions with a certainty score equal to 1 to a maximum of 1. e.g., all 55 questions with a confidence level equal to 4) [37, 43].

RESULTS

In the Baixada Santista River basin region, it is common to build fishing enterprises in the rural areas near small streams (Figure 1 and Figure 2) that are generally used for water collection. They can also be found in urban areas surrounded by fragments of Atlantic Forest (Figure 1). In these fishing grounds, there is heterogeneity regarding the color pattern of the waters of fish tanks and lakes, ranging from intense green to metallic red. The presence of fingerlings, as well as different birds such as herons, “quero-queros” and vultures (Charadriidae, Ardeidae, and Cathartidae, respectively) can also be observed in the vicinity of the tanks. Birds play an important role in the dispersal of species.

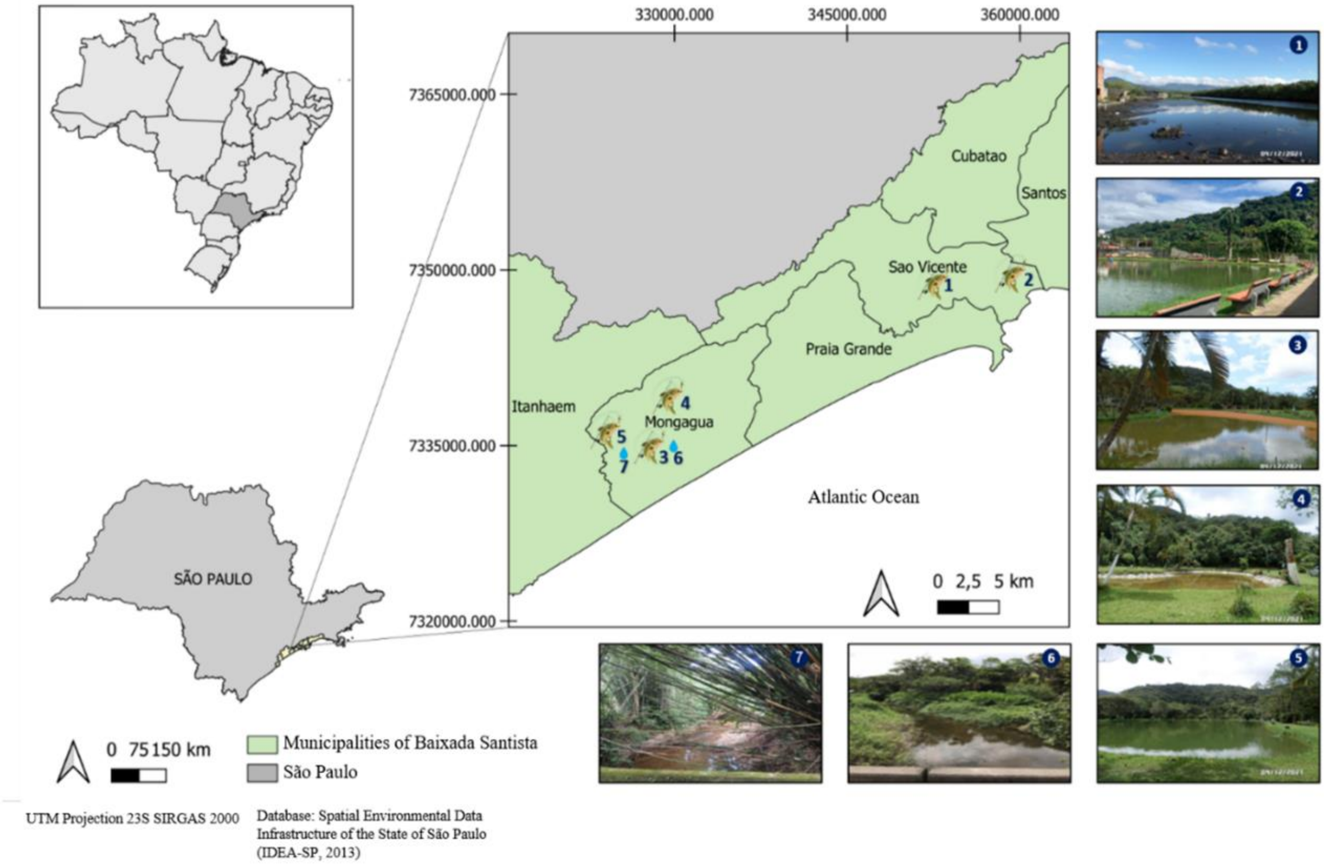

Figure 1. Study area in the Baixada Santista watershed, coastal region of the São Paulo state, Brazil.

In the rural area of the municipality of Mongaguá, on the fishing route, there is a vast presence of streams that connect to the Aguapéu River, a tributary of the Itanhaém River, and the Preto River (Figure 2). It was possible to verify that all the evaluated fishing grounds already have problems with escapes. Two-thirds of the fishing suffered from the transshipment of artificial tanks and lakes, due to heavy rains that affected the region. At the time, the river level rose, reaching the growing tanks. Another cause for species escape is the drainage system. When the maximum volume of the cultivation tanks is exceeded, the water from the tanks, coming from the springs, goes to the dividing ditch between the land, then into the streams, and then to the nearby rivers.

Figure 2. Streams (6 e 7) located near to visited fishing grounds, which connect with the Aguapeú River, a tributary of the Itanhaém River. Map A: modified from *Google Maps*. Map B: modified from CBH-BH - http://www.cbhbs.com.br/index.php/sig-web-bs/.

From the data collection with the fisheries managers, it was identified that of the 14 species cultivated in the enterprises, only two, the Trahira and Jundiá, are native species (Table 1). Most of the species created originate from other continents and/or hydrographic basins. Additionally, hybrids such as Patinga, Tambacu, Tambatinga, and mutant Tilapia strains, such as Tilapia Saint Peter and strains from breeding programs such as Tilapia Gift (Genetically Improved Ly Farmed Tilapia) [44].

Table 1. Cultivated species in fishing grounds in the Baixada Santista Watershed.

Common name	Scientific name	Native/Non-native	Native distribution	Fishing grounds		
				1	2	3
African Catfish	*Clarias gariepinus*	Invasive	Africa	x	x	x
Common Carp	*Cyprinus carpio*	Non-native	Eastern Europe and Western Asia	x	x	x
Grass Carp	*Ctenopharyngodon idella*	Non-native	Asia	x	x	--
Curimba	*Prochilodus* spp	Non-native	Paraná-Paraguay and Paraiba do Sul River basin	x	-	--
Jundiá	*Rhamdia quelen*	Native	Central and South America	x	-	--
Pacu	*Piaractus mesopotamicus*	Non-native	Paraná-Paraguay River basin	x	x	x
Patinga	♀ *P. mesopotamicus x* ♂ *P. brachypomus*	Non-native	-	x	--	--
Tambaqui	*Colossoma macropomum*	Non-native	Amazon and Orinoco basins	x	x	x
Tambacu	♀ *C. macropomum x* ♂ *P. mesopotamicus*	Non-native	-	x	x	--
Tambatinga	♀ *C. macropomum x* ♂ *P. brachypomus*	Non-native	-	--	x	--
Nile Tilapia	*Oreochromis niloticus*	Non-native	Africa	x	x	x
Saint Peter Tilapia	*O. niloticus or O. aureus*	Non-native	Africa	x	x	x
Tilapia Gift*	*T. rendalli or O. niloticus*	Non-native	Africa	x	-	--
Trahira	*Hoplias malabaricus*	Native	Central and South America	x	x	x

♀= female; ♂ = male; -- = not reported; * Genetically Improved Farmed Tilapia

Table 2 presents the summary data, including the main characteristics of the enterprises. The municipality of Mongaguá has the highest concentration of fishing-type enterprises in the Baixada Santista River basin region (Figure 1). These enterprises have been operating for at least 20 years. On average, they cover an area of 50,000 m^2 and have at least 3 artificial tanks or lakes per development, with an average depth of 1.5 m and areas ranging from 800 to 6000 m^2. Fish are typically purchased in adult form from fish farms in the interior of São Paulo (~ 200 - 300 km distance) or Minas Gerais State.

Table 2. General features of fishing grounds located in the Baixada Santista Watershed. Data are presented as mean ± standard deviation.

Enterprise Characteristics	
Time of existence (years)	20.3±10
Owner's time in the role (years)	16.0±5.5
Total area (m^2)	50.000±16.000
n° of tanks	3.3±0.6
Lake's area (m^2)	800-6.000
Minimum Depth (m)	1.0±0.6
Maximum Depth (m)	1.7±0.3
Visiting/per day	25±13
Food offered	Portion

n=3

Upon acquisition, the fish are acclimatized for a few minutes or hours with the water of the lakes before being discharged into the tanks using dip nets. No quarantine of the animals is conducted. While the feed is the only recommended food, there is no specific control to prevent other types of food from being offered to the fish. Regarding the monitoring of the physicochemical parameters of the water quality in the growing tanks, two-thirds of the managers reported conducting such monitoring (Figure 3a). However, there is no standard procedure for evaluating the parameters or frequency of monitoring. In addition, there is no control and/or monitoring of any microbiological parameters or evaluation of fish health. Most managers believe that the type of fish species does not have a significant impact on water quality (Figure 3b). The biggest concerns are related to species predation and the possible introduction of pathogens (Figure 3c), particularly in African Catfish and Grass and Hungarian Carp.

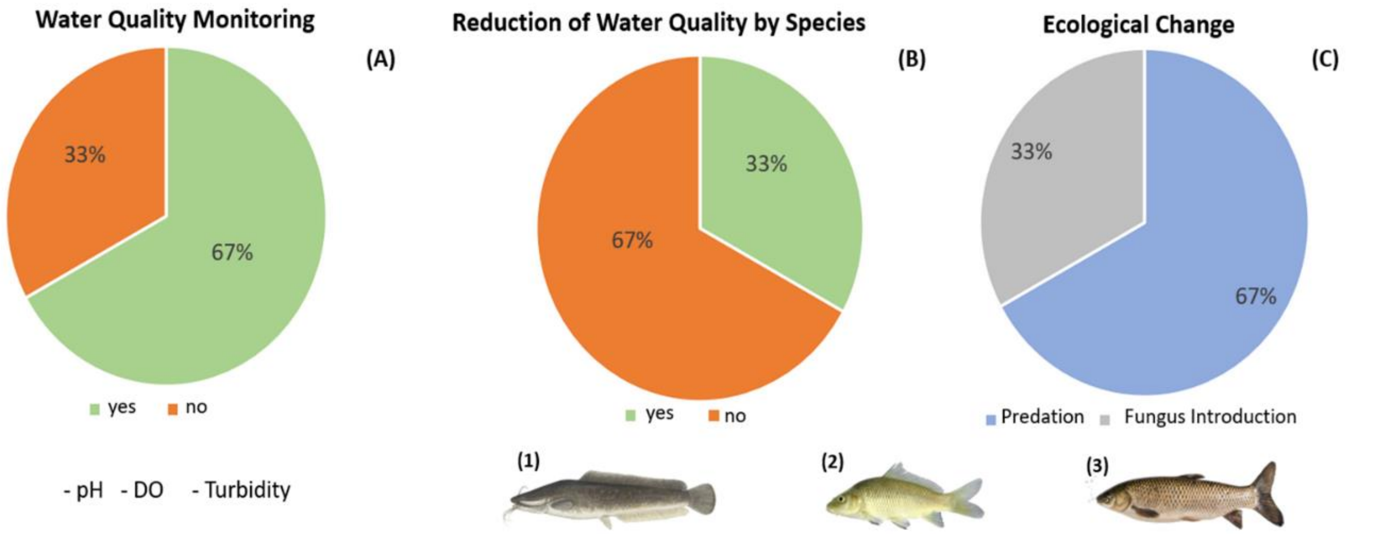

Figure 3. Physicochemical and ecological parameters reported by fisheries managers. A) Water quality monitoring and respective analysis performed (pH, dissolved oxygen - DO - and Turbidity). (B) Species reported to reduce water quality and (C) Species reported to promote change in the interaction dynamics and introduction of pathogens into artificial lakes. (1) African Catfish (*Clarias gariepinus*), (2) Common/Hungarian Carp (*Cyprinus carpio*). (3) Grass Carp (*Ctenopharyngodon idella*). Illustrations of fish species obtained from free access image banks https://www.pngkey.com/maxpic/u2w7e6t4w7a9o0w7/; https://www.pngkit.com/bigpic/u2q8e6y3i1t4e6r5/; https://www.seekpng.com/ima/u2y3q8y3y3a9r5t4/_ By Chad Thomas

Regarding the hybridization of different fish species, most managers believe that it does not occur frequently. However, when it does happen, it is related to the crossing of Pacu (*Piaractus mesopotamicus*) and Tambaqui (*Colossoma macropomum*) (Figure 4a). In terms of diseases, managers reported issues with *Lernaea* sp. or "anchor worm" (crustacean copepoda, Lernaeidae) and gill isopods (crustacean ectoparasite) in Nile Tilapia (*Oreochromis niloticus*), and fungi related to African Catfish (*Clarias gariepinus*) (Figure 4b). Additionally, it was discovered through interviews that Trahira (*Hoplias malabaricus*) arrives in the tanks with the spring water, and some managers use this fish to control Tilapia fingerlings because it reproduces in the tanks.

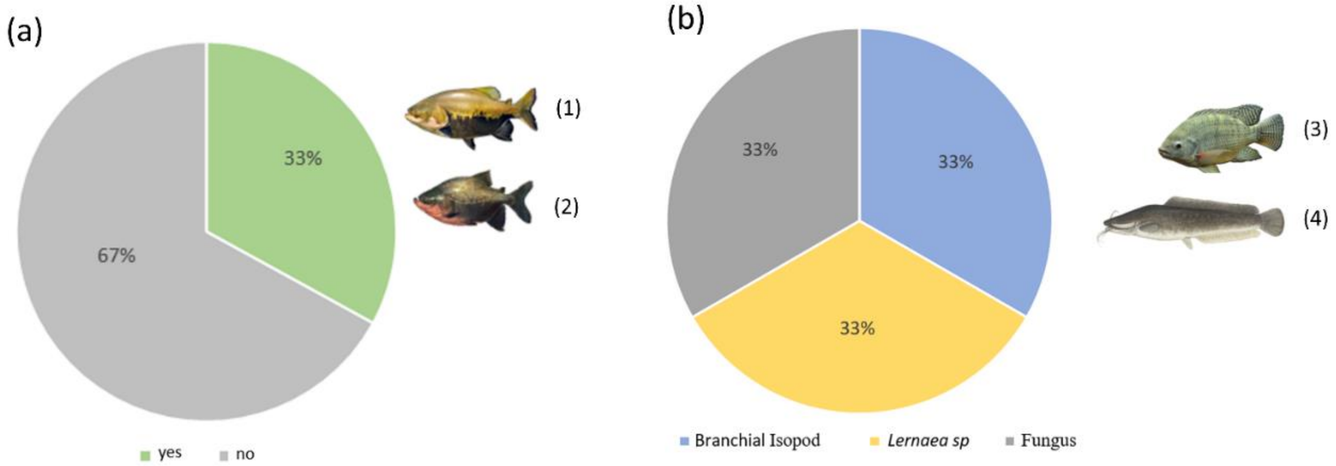

Figure 4. (a) Crossing between different fish species reported by fisheries managers. (1) Tambaqui (*Colossoma macropomum*) and (2) Pacu (*Piaractus mesopotamicus*). (b) Fish species most frequently reported in fisheries due to disease and/or the presence of parasites. (3) Nile Tilapia (*Oreochromis niloticus*), (4) African Catfish (*Clarias gariepinus*). Ilustrations of fish species obtained from free access image banks: https://www.pngkey.com/maxpic/u2w7e6t4w7a9o0w7/; https://www.pngkey.com/detail/u2e6i1a9a9q8e6u2_nile-tilapia-oreochromis-niloticus/; https://www.gratispng.com/png-7b8w4k/download.html

In terms of invasion risk, five out of the six fish species assessed were found to pose a high invasion risk in terms of their harmful characteristics (Table 3 and Figure 5a). *Clarias gariepinus* obtained the highest score in the AS-ISK, followed by *O. niloticus*, *C. carpio*, and *H. malabaricus*. *Colossoma macropomum* presented a medium risk of invasion in terms of their harmful characteristics. Although *P. mesopotamicus* had a score above 18.5, this species was at the lower end of the high invasion risk classification.

Considering the impacts on the commercial and environmental sectors, the five species with a high risk of invasion pose a low risk of impact (Figure 5b). In the environmental sector, *C. gariepinus* received the highest risk score, followed by *C. carpio* and *O. niloticus*. In the commercial context, the same profile was observed. The species with the lowest risk in these sectors were *C. macropomum* and *P. mesopotamicus*.

Table 3. Invasive potential of fishes species in the Baixada Santista Watershed, concerning the obtained scores by AS-ISK to the Basic Risk Assessment (BRA) and BRA + CCA (Climate Change Assessment).

	BRA		BRA+CCA		CF	
Species	**Score**	**Risk**	**Score**	**Risk**	**BRA**	**CCA**
Clarias gariepinus	55.0	high	67.0	high	0.80	0.50
Cyprinus carpio	36.5	high	46.5	high	0.74	0.50
Colossoma macropomum	15.0	medium	11.0	medium	0.76	0.50
Hoplias malabaricus	27.0	high	39.0	high	0.71	0.50
Oreochromis niloticus	40.0	high	52.0	high	0.81	0.50
Piaractus mesopotamicus	20.0	high	20.0	high	0.70	0.50

CF: confiance factor

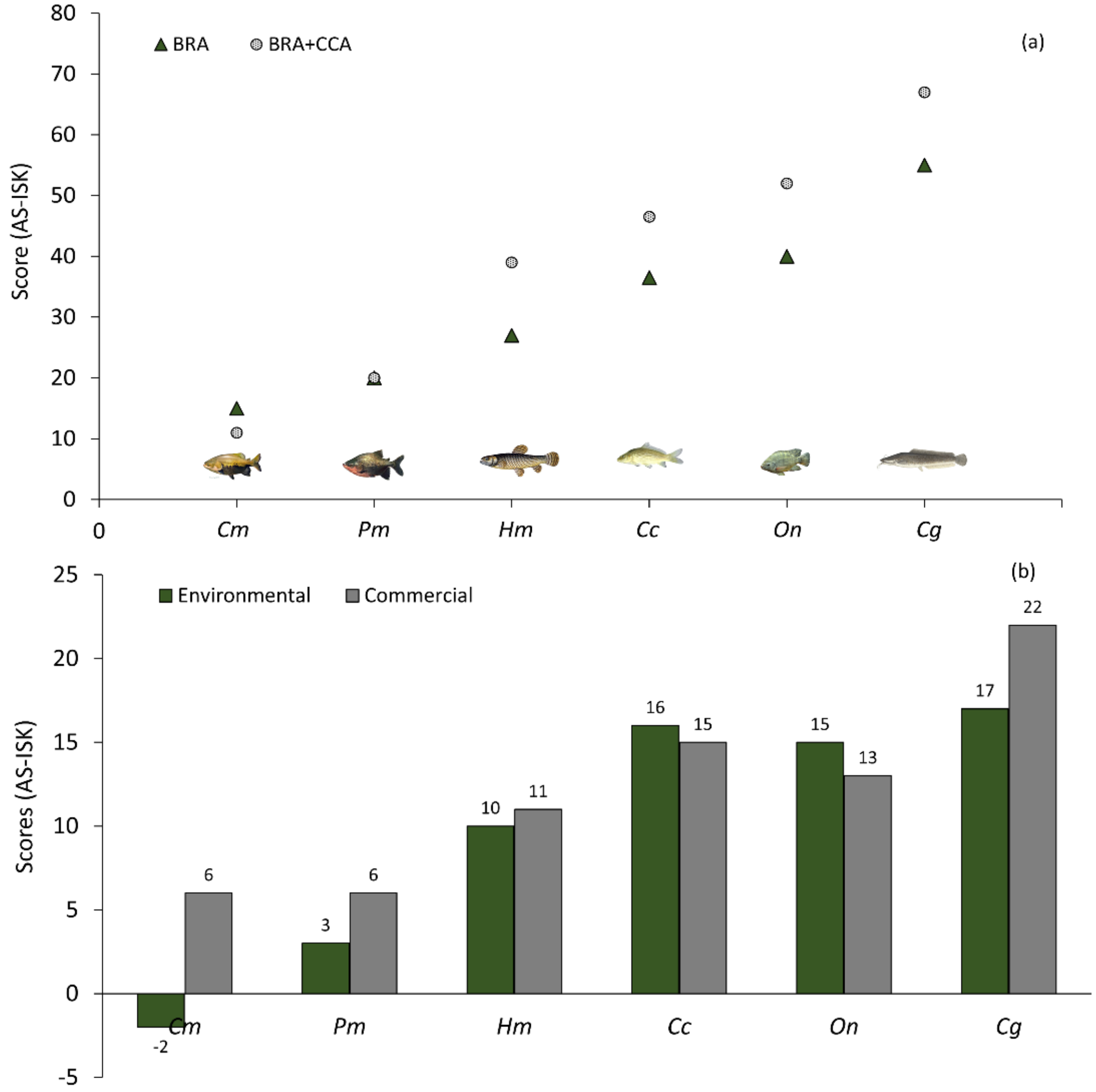

Figure 5. Scores obtained in AS-ISK protocol for the six species most cultivated in fisheries from the Baixada Santista watershed, represented by the harmful characteristic of the species Use authorized by the author: *Piaractus mesopotamicus Picture by* Leonard Lovshin, 1999. Illustrations of fish species obtained from free access image banks: https://www.pngkey.com/maxpic/u2w7e6t4w7a9o0w7/; ttps://www.pngkey.com/detail/u2e6i1a9a9q8e6u2_nile-tilapia-oreochromis-niloticus/; https://www.seekpng.com/ima/u2y3q8y3y3a9r5t4/_ By Chad Thomas; https://www.gratispng.com/png-7b8w4k/download.html; J. F. Hennig - Bibliothèque nationale de France.

DISCUSSION

Global catches in inland waters account for approximately 12.5% of total fishing production. According to the latest FAO report [45], world fishing production in inland waters has grown by 53% since 1995, reaching 12 million tons in 2018 from 6.4 million tonnes in live weight. Brazil ranks 13th in the world, but it is the main producer of fish in continental waters in South America, due to the Amazon basin, which is two-thirds in Brazil. The country is also the sixth-largest producer of fish globally [45, 46], with other basins such as the watershed of Paraná (including São Paulo), São Francisco, and Tocantins-Araguaia contributing to national production [47].

Although fishing grounds are primarily dedicated spaces for leisure fishing, the species kept in these areas often come from fish farms. The increase in fishing in continental waters and the rise in the number of fishing grounds have contributed to the growth of fish farming, usually with introduced species. As a result, the species cultivated in these farms reflect production in Brazilian territory, with a strong tendency towards exotic and hybrid species [25]. The lack of specific regulations for this type of enterprise regarding sustainable practices and management can result in non-native species escaping into natural environments, highlighting the importance of assessing and understanding their potential impact on the environment and ecosystem.

Birds are important dispersers of species, and their presence around fish breeding tanks in the Baixada Santista watershed can promote the dispersion and introduction of more resistant species, such as tilapia and African catfish, into natural watercourses. Escapes from drainage systems during floods are also possible routes of species dispersion in neighboring watersheds, such as the Ribeira de Iguape River [48]. The absence of management practices, such as quarantine measures, to control the spread of possible pathogens and feeding control measures, can lead to water quality loss in tanks and the reduction of the health of the animals present. In this study, crossbreeding of species such as *P. mesopotamicus* and *C. macropomum*, has been reported in the fishing tanks. These species require hormonal stimulation to reproduce, as they are rheophilic fish that migrate to reproduce [49], making their crossing in fishing grounds not a significant problem.

In recent years, many decisions support tools have been developed to assist fisheries managers in assessing the risk of invasion of non-native species in natural water. In this sense, the programs FISK (*Fish Invasiveness Screening Kit*) and AS-ISK have been applied for this purpose in several countries in Europe, United States of America and South Korea [37, 43, 50], to categorize the impacts caused by the introduction of non-native species, also considering possible effects of climate change. While the use of FISK or AS-ISK is still limited in Brazil, some data have been collected in the watershed of the Paraná and Rio Grande do Sul States [51, 52].

Clarias gariepinus, *O. niloticus, C. carpio,* and *H. malabaricus* are species with biogeographic and bioecological characteristics that give them a high potential for invasiveness. This potential is related to factors such as high reproductive rate, early sexual maturity (in the case of *O. niloticus* and *C. gariepinus)*, predation, competition, and introduction of parasites [53, 54, 55]. If these species are not managed properly, the likelihood of them invading new watercourses increases. *Clarias gariepinus* is particularly invasive due to its adaptability to diverse environments with low environmental quality and low oxygen concentration. This species can breathe out of the water and can move from one tank to another. It is known for its negative impact on native species, including predation and the introduction of parasites such as *Contraceacum* sp. [56, 57, 58].

Oreochromis niloticus is a territorial species that is quite opportunistic and has a high rate of fecundity. Males of this species incubate eggs in their mouth, and like African catfish it has a high salinity tolerance, being found in coastal rivers and at the estuary limit [54]. *Cyprinus carpio* and *O. niloticus* have benthic eating habits, which can increase the turbidity of the water and harm visual predatory species such as *H. malabaricus*. *Cyprinus carpio* is associated with the introduction of "anchor worm" (*Lerneae cypriceae*), while *O. niloticus* is associated with the introduction of at least seven-gill parasites, including six monogenoids (Platyhelminthes) and a crustacean copiscan (*Lamproglena monodi*) [55].

Hoplias malabaricus is a carnivorous and predatory species [53] that is one of the few native species cultivated in the artificial lakes of fishing grounds. While it has a high potential for invasion, it also presents medium risk in the commercial and environmental sectors. In case of an increase in the populations of *H. malabaricus* in natural water courses due to escapes in the fishing grounds, there may be a change in the dynamics of ecological interactions. Additionally, this species is directly subject to the introduction of pathogens from other regions in the growing tanks. Thus, in case of escape, it can lead pathogens to wild specimens. *Colossoma macropomum* and *P. mesopotamicus* are species with low risk of invasion due to their specific characteristics regarding reproduction and feeding. They are rheophilic species that need to migrate to reproduce and are known as fruit-dispersing species [49, 59].

Although the potential impact of fishing grounds on the environmental and commercial sectors is not observed, these establishments act as potential introducers of non-native fish species in natural water courses. The dispersal routes that these establishments provide contribute unintentionally to the escape of cultivated species, such as water drainage systems of tanks that interconnect with natural areas, or by problems intrinsic to the region, such as floods that lead to the transshipment of tanks. More interviews with managers of other fishing grounds in the region are recommended to validate this profile.

In conclusion, it is important to manage and contain these species to reduce the risk of invasion and the negative impact on native species and ecosystems. The cultivation of low-risk species such as *C. macropomum* and *P. mesopotamicus* in fish farming systems and fishing grounds should be encouraged.

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